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DEVELOPING WEARABLE EMOTIONAL ASSISTIVE TECHNOLOGY FOR PEOPLE WITH AUTISM SPECTRUM DISORDER

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AUTISMIKIRJOON KUULUVILLE SUUNNATUN TUNNETILOJA MITTAAVAN AVUSTAVAN TEKNOLOGIAN SUUNNITTELU JA PROTOTYPOINTI

Esineiden internet on jo nykyään osana jokapäiväistä elämäämme. Terveydenhuollon tarjoajat ovat vuoden 2016—2017 aikana kasvattaneet Internet-verkkoon kytkettyjen laitteiden määrää jopa 86 %. Älyrannekeiden suosiosta johtuen samaan aikaan kasvaa myös puettavien laitteiden kysyntä. Tähän kun yhdistetään viimeisen 50 vuoden aikana autismikirjon maailmanlaajuinen yleistyminen, niin nykyteknologiaa hyödyntämällä pystyttäisiin auttamaan miljoonia ihmisiä ympäri maailmaa.

Opinnäytetyön aiheena oli kehittää rannekemallinen puettava laite, joka mittaa ihmisen hikirauhasten laajentumisesta aiheutuvan sähkönjohtavuuden muutoksen. Tästä sähkönjohtavuuden muutoksesta on mahdollista tunnistaa ihmisen reaaliaikainen tunnetila, jonka avulla voidaan auttaa ja helpottaa autismikirjoon kuuluvan ihmisen omaa, läheisten ja hoitohenkilökunnan arkea. Prototyyppi toteutettiin käyttämällä galvaanisen ihoreaktion mittaavaa anturia yhdistettynä Cypress PSoC 6 -mikrokontrolleriin.

Teoriaosuudessa avataan kevyesti sitä mitä on autismi ja kuinka se vaikuttaa autismikirjoon kuuluvan ihmisen elämään. Mikroilmeiden historia juontaa juurensa 1960-luvulle, jolloin havaittiin ihmisten tahattomat mikroilmeet. Ihmisellä on seitsemän yleisintä tunnetilaa, jotka voidaan havaita näiden mikroilmeiden avulla. Ihmisen sympaattinen hermosto kontrolloi pieniä hikirauhasia, joihin aivojen tunteita säätelevä limbinen järjestelmä on yhteydessä. Tämä mahdollistaa hikirauhasten laajentumisesta kerättävää tietoa hyväksikäyttäen tunnetilojen havaitsemisen teknologian avulla. Lisäksi opinnäytetyössä tutustutaan kahteen jo markkinoilla olevaan vastaavalla teknologialla toimivaan laitteeseen.

Opinnäytetyön tuloksena syntyi yksinkertainen galvaanisen ihoreaktion mittaava sensori, joka lähettää kahden sensorin välillä mitatun sähkönjohtavuuden muutoksen luettavaan muotoon asynkronisen sarjaliikenteen avulla tietokoneella olevaan pääte-emulaattoriin. Tästä datasta on mahdollista piirtää kuvaaja, josta voidaan algoritmejä hyödyntäen tunnistaa ihmisen reaaliaikainen tunnetila.

AVAINSANAT:

avustava teknologia, Cypress PSoC 6, galvaaninen ihoreaktio, tunteet, autismi

BACHELOR'S THESIS | ABSTRACT

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DEVELOPING WEARABLE EMOTIONAL ASSISTIVE TECHNOLOGY FOR PEOPLE WITH AUTISM SPECTRUM DISORDER

The Internet of Things is already part of our daily lives. During 2016-2017, healthcare providers have increased the number of IoT devices up to 86%. Wearable devices have become really popular, because of the smartwatches. While the usages of IoT devices are constantly growing, so is the prevalence of Autism Spectrum Disorder. ASD has been increasing globally during the past 50 years. With modern technology it is possible to create a device that could help millions of people around the world.

The goal for the thesis was to develop a wearable assistive device that measures the conductance of the skin caused by the expansion of eccrine sweat glands. Using that data it is possible to identify people's emotions in real time. This technology can help people with autism spectrum disorder, their relatives and nursing staff. A simple prototype is created with a Cypress PSoC 6 microcontroller with a Grove Galvanic Skin Response Sensor.

The theoretical part of the thesis focuses on the autism spectrum disorder and how it affects their lives. The history of micro expressions dates back to the 1960s' when the seven most common emotions were detected. The sympathetic nervous system controls the eccrine sweat glands, which are connected to a human limbic system. The limbic system is responsible for controlling these seven most common emotions. There are also two wearable devices already in the market that are using similar technology.

The result of this thesis was a working galvanic skin response sensor that measures conductivity between the two sensors. Data is transformed to a readable format and then transmitted via asynchronous serial communication to the computer terminal emulator. From this data it is possible to draw a graph using algorithms to identify different human emotions.

KEYWORDS:

wearable technology, Cypress PSoC 6, galvanic skin response, emotions, autism spectrum disorder

CONTENT

FIGURES

EQUATIONS

PICTURES

TABLES

List of Abbreviations (OR) Symbols

GSR	Galvanic Skin Response

EDA	Electro Dermal Activity
ASD	Autism Spectrum Disorder
MCU	Microcontroller Unit
BVP	Blood Volume Pulse
ANS	Autonomic Nervous System
WHO	World Health Organization
PSoC	Programmable System-On-Chip
PWM	Pulse-Width Modulation
UART	Universal Asynchronous Receiver Transmitter
ADC	Analog-to-digital converter
SAR	Successive Approximation Register
IOT	Internet of Things
FACS	Facial Action Coding System

1 INTRODUCTION

We are living in an era of Internet of Things (IoT). The healthcare providers have increased their IoT connections by 86% during the past year (Forbes, 2017). Wearable devices have become really popular mainly because of the smartwatches, like the leading brands such as Apple Watch and Android Wear. According to Interantional Data Corporations (IDC) report, smartwatches market grew 60.9% during the past one year in 2017. To answer highly growing markets, Cypress Semiconductor Corp. released in late 2017 their new PSoC 6 microcontroller unit (MCU) which is especially made for prototyping a low-power wearable IoT devices.

While the use of IoT devices are constantly growing, so is the prevalence of Autism Spectrum Disorder (ASD). ASD has been increasing globally during the past 50 years and estimated 1 in 160 childrens worldwide has an ASD (WHO 2017).

The main goal of this project is to start prototyping a wearable emotional assistive device for people with ASD. Cypress PSoC 6 MCU will be used as a platform for the prototype with a Galvanic Skin Response -sensor. This thesis explains what is emotional assistive technology, how it can be helpful for people with ASD and how human emotions could be measured. Thesis will also give an answer whether the PSoC 6 will be viable platform for prototyping IoT device if the user has only minor knowledge of embbedded systems and microcontrollers.

2 UNDERSTANDING EMOTIONS AND AUTISM SPECTRUM DISORDER

2.1 Autism Spectrum Disorder

Autism spectrum disorder is a brain-based disorder that affects how an individual perceives the world. It can cause different challenges related in person behaviour, social interaction skills and the way of learning. Some people with ASD is able to live relatively normal lives while others need continued specialist support. (Autism Science Foundation 2018)

There is usually a significant emotional and economic burden among people with ASD and their families. Parents and a caregivers can has a positive impact on the person’s wellbeing and quality of life when behavioural treatment and skills training programmes are used (WHO 2017).

In 2013, Mazefsky and White published an article about emotion regulation and how it can be compromised in ASD. The article states that we lack evidence-based tools that determine accurately persons emotion regulation. Identifying emotions through the self-evaluation is likely to be insufficient for people with ASD, so observational approaches can yield important information.

A wearable device that accurately identifies childrens current emotional state could have a major medical and scientific advancement when the caregivers and parents have a possibility to identify stressful situations in real time and take possible actions to prevent any additional stress caused to the children with ASD. This could improve person’s wellbeing and might also allow the person’s to self-evaluate and identify their current emotions.

2.2 Emotions and micro expressions

History of understanding and studying human emotions goes as far as the late 1800s when Charles Darwing proposed that humans and animals both have innate or universal expressions (Darwin C. 1872).

In 1966 two scientists, Haggard and Isaacs were the first people to discover the existence of micro expressions. They found out that patient's face changed dramatically during five frames of film when they scanned motion picture films that contained psychotherapy hours about non-verbal communication between a patient and a therapist. They were not able to notice these expressions while played at the normal 24 frames per second speed, but when slowed down or examined frame by frame these changes were noticable (Haggard E. Isaacs. K. 1966, 154).

Paul Ekman started to study deception in the 1967 just after Haggard and Isaacs has discovered micro expressions. With his friend Wallace V. Friesen, Ekman examined his patients that committed suicide after they were lying about their depression. Ekman and Friesen started to inspect the patients films in slow motion and they saw strong negative micro expressions that the patients were trying to conceal during the interviews where they lied (Ekman 2017).

There are seven basic micro expressions, disgust, anger, fear, sadness, happiness, surprise and contempt. These micro expressions are all universal, so it does not matter where you are from or what is your cultural background. (Ekman 2017). Even when micro expressions are universal. There are some cultural differences that affect people's emotions. In 1972, Paul Ekman filmed college students from Japan and United States. When they were alone, their facial expressions were identical, but when someone else was presence, Japanese students tried to conceal their unpleasant feelings more than the American students. (Edwards V. 2013, Ekman P. 1977, 100)

Micro expressions are brief; they occur within 1/25 of a second while exposing person's true emotions. Micro expressions show people true emotions even when they are attempting to conceal their emotions consciously or unconsciously, i.e. micro expressions cannot be hidden. (Ekman 2017)

2.2.1 Facial Action Coding System

In 1970 Swedish anatomist Carl-Herman Hjortsjö analysed the human facial expression and mimetic functions of the facial muscles. Hjortsjö recognized 23 different units of movement and he analysed their interaction and contraction strengths. (Hjortsjö, 1970). Based on the Hjörtsö's research Paul Ekman and Wallace V. Friesen published their own research in 1976. They created a Facial Action Coding System (FACS) to taxonomize human facial movements (Ekman, Friesen 1976, 58). In 2002, Ekman and Friesen published an updated FACS manual that includes 27 facial Action Units (AU) and 52 additional movements including head and eye positioning. FACS also includes intensity of the facial expression for each AU separately. AU scale is A to E where E is maximum and A is only a trace. (Prince E. etc.). FACS can be used in coding to animate realistic human expressions and emotions. There are several different facial recognition software solutions that automatically analyse facial expressions from videos and images. They are all based on FACS.

2.2.2 Facial recognition software

One of the leading companies in the field of facial recognition software is the Affectiva. They have analysed over 6 million faces with their software. Their Emotion AI measures the facial expressions of emotion with any optical sensor or just with a normal webcam. Algorithm identifies key spots in the face and deep learning algorithm analyses pixels in those areas to classify facial expressions. Different combinations of these facial expressions signifies specific emotions. Emotion AI measures 7 basic emotions: anger, contempt, disgust, fear, joy, sadness and surprise. Facial data has been analysed from 87 different countries and they continuously test their algorithms to achieve the most reliable and accurate results (Affectiva 2017)

2.3 Similar products on the market

In the current market there is basically no competition among the emotional assistive technology that facilitates the recognition of basic emotions. Current wearable IoT devices concentrate on different target audience, even when they have the needed sensors and capability to measure emotion and human behaviour which is not under cognitive control. These products also tend to be very expensive and inaccessible among low-income families. Keeping the cost at the level that is affordable by low-income families gives their opportunity to improve their quality of life, while reaching even wider target audience in the market.

2.3.1 Empatica E4

Empatica E4 wristband is marketed for clinical quality observation, that obtains accurate and precise real-time physiological data. It contains different types of sensors which measures Blood Volume Pulse (BVP), Electro Dermal Activity (EDA), Infrared Thermopile for reading skin temperature and 3-axis Accelerometer. This bracelet is designed more for laboratory and research use because it collects raw data and it comes with Application Programming Interface (API) for developers to build and develop mobile applications for Android or iOS. Almost 1700$ price tag makes this product basically inaccessible for personal use (Empatica 2017).

2.3.2 Empatica Embrace

With slightly under 250$ price tag, Empatica Embrace is way more affordable for personal use than E4. It has a stylish and sleek design for everyday use. It has an EDA sensor, Gyroscope, 3-Axis Accelerometer and a Peripheral Temperature Sensor. They market it with Seizure Detection, Sleep Monitoring and Activity Tracking. The target audience with this device is way more “consumer first” rather than for scientific research. The target audience is not for people with ASD and it has no emotion recognition (Empatica 2017).

3 EMOTIONAL ASSISTIVE TECHNOLOGY

Besides facial expressions, our skin is an essential source of information when studying human emotions. Our skin works as an immune system that protects our body from outside threats such as impacts, bacteria, solvents and toxic chemicals. The temperature of the body is controlled by the skin through peripheral blood circulation, piloerection and sweat emission as known as thermoregulation. Also you sense environment through your skin with different receptors that measures the temperature, pressure and pain. Human sweat secretion cannot be controlled consciously. It is controlled by our autonomic nervous system (ANS) which is connected to our sweat glands (Figure 1) (iMotion 2015, 6, 7).

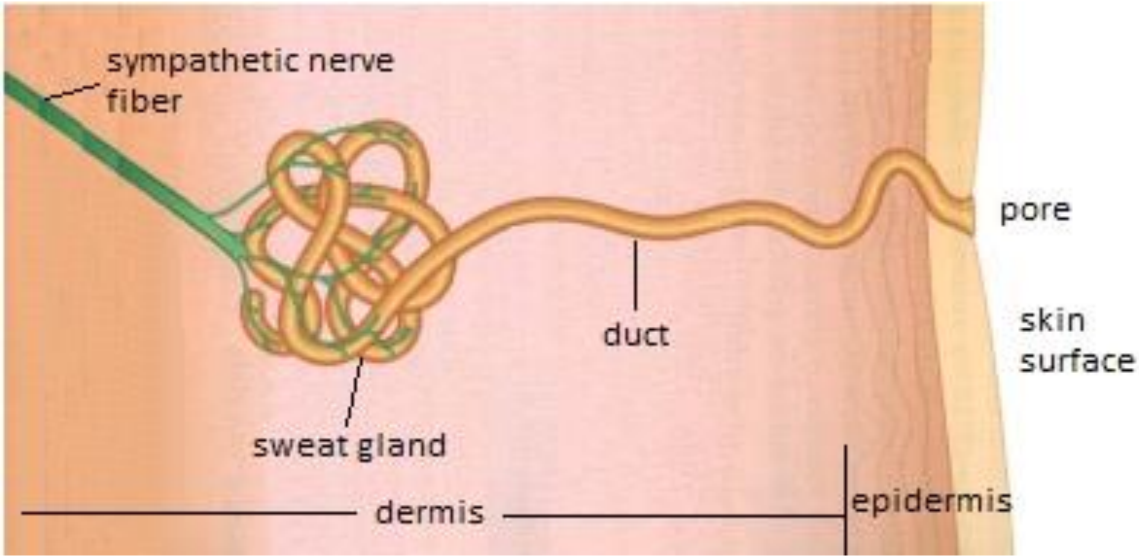


Figure 1. Illustration of human skin anatomy shows how ANS is connected to our sweat glands. (Ivo Tarfusser 2018)

Human skin contains approximately 3 million sweat glands, where the highest density of the glands is located on the palms and soles. The palm of the hand has an estimated 500 glands per cm^2 (Saylor 2010).

3.1 Galvanic Skin Response

Galvanic Skin Response (GSR) research dates back to the year 1849 when German physician Emil du Bois-Reymond discovered that electrical discharge was related to the peripheral passage of the nerve impulse (Pearce 2010). GSR is measured by applying a low constant voltage to the skin and measuring the change in skin conductance (Boucsein 2012, 2). Sweat glands secrete moisture through pores to the surface of the skin and while sweating is affected by your autonomic nervous system, different emotions cause your sweat glands secrete various amount of moisture throught the pores. Variation in moisture levels return different electrical flows. (iMotion 2015, 7)

When measuring skin conductance we can wirte Ohm's Law as $R=V/I$ (Equation 1). R is the skin resistance which equals the voltage V applied between two electrodes on the skin. V is divided by I which is the current passed through the skin. The voltage runned through the skin is so small that cannot be perceived by the invidual. (Wagner. & Wagner 2013, 2)

$$R \equiv \frac{V}{I}$$

Equation 1. Ohm's Law

The typical units of GSR are microsiemens (µS) or micromho (µmho). 1µS is equal to 1µmho, so these units are equivalent. (Braithwaite etc. 2013, 4)

3.2 Emotional Nervous System

We have now covered some basics of human emotions, what they are and how they are measured. Neverthless yet to fully understand the concept and relationship between GSR and emotions we need take a quick brief in two parts the in human nervous system. The limbic system and the autonomic nervous system.

The limbic system includes a set of a complex brain structures, i.e. hypothalamus, amygdala, hippocampus and cingulate gyrus (Figure 2) (Swenson 2006, 9). Our emotional life is primarily driven by the limbic system and besides that it has a role with the formation of memories. Hypothalamus is one of the most active part of our brain and it controls a functioning of the autonomic nervous system. Hypothalamus is responsible for our pulse, blood pressure, breathing and sexual arousal (Boeree 2009). The amygdala is especially responsible for emotional content that includes behavioral, autonomic and endocrine responses. Amygdala responds especially to fear and anxiety. Amygdala is also strongly implicated in emotional memory. (Anderson etc. 2001, 1) The hippocampus is mainly responsible for our memory functions. Hippocampus encodes and retrieves memories (Boeree 2009).

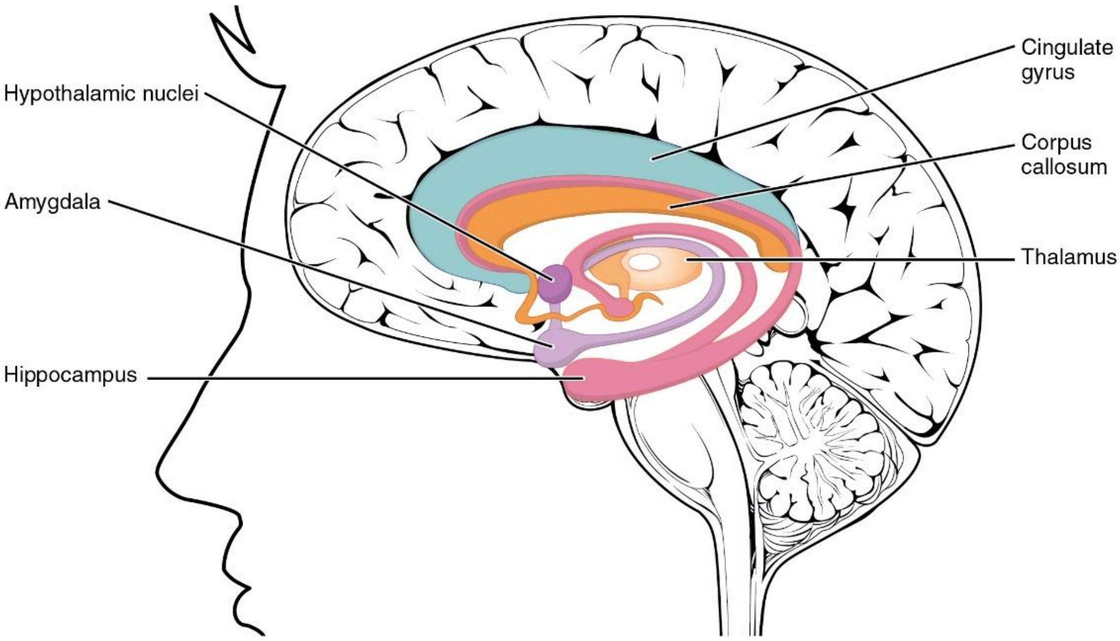


Figure 2. The human limbic system (Wikimedia Commons 2018)

The Autonomic Nervous System has two parts. First one is the sympathetic nervous system and the second one is the parasympathetic nervous system (Figure 3).

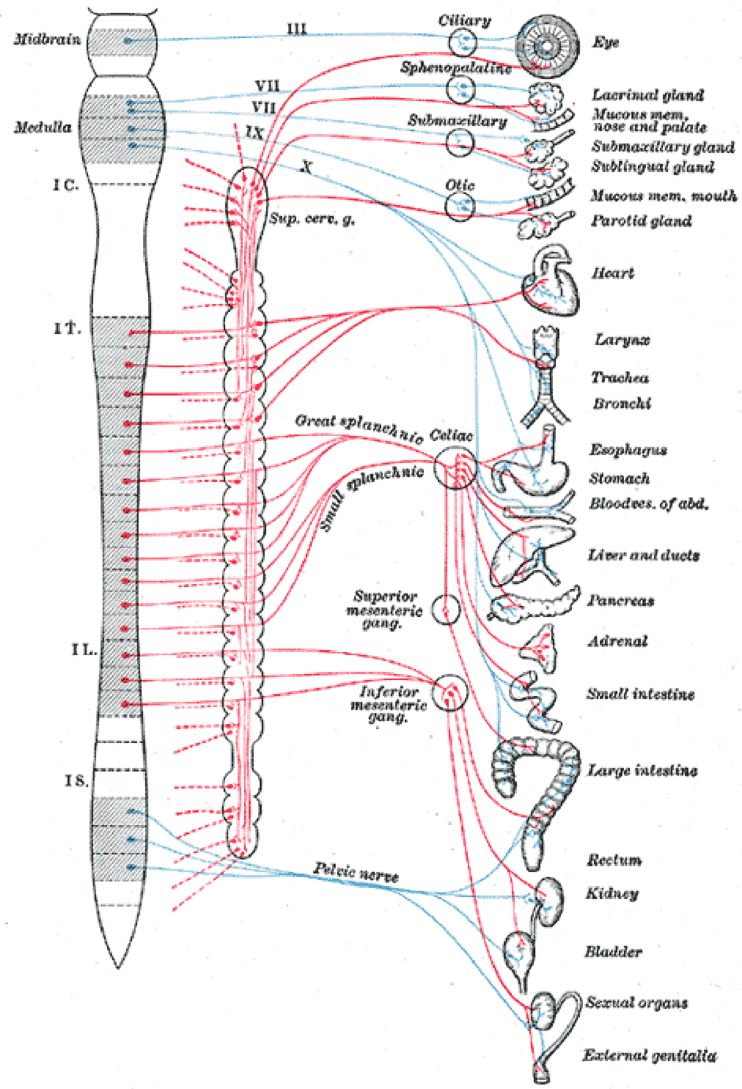


Figure 3. The Autonomic Nervous System. Red lines are sympathetic nervous system and blue lines are for parasympathetic nervous system. (Wikimedia Commons 2018)

The sympathetic nervous system stimulates the sweat glands, dilates and constricts the blood vessels and increases heart rate. The parasympathetic nervous system on the other hand decreases the heart rate receives information about blood pressure and activates the salivary gland (Boeree 2009). ANS connects your brain and internal organs by spinal nerves.

3.3 Signal noise and median filter

There are a lot of different factors that affect GSR sensor reliability and the collected data, i.e. different types of noises. One of the concerns is the continuity of the signal which is affected by the contact between dry-electrodes and the skin. The quality of the signal depends on how snuggly the electrode is contacted with the skin or how dry skin the person has. Touching the device itself creates a noise in the signal. Excercising, rise in the temperature or a fast physical movement affects GSR data even when there is no emotional stress involved. (Bakker, etc. 2011, 575, 576)

GSR data should be filtered because of the noise. A good way to filter noise from GSR signal is to use a median filter. The median filter is used in image processing to reduce noise and periodic patterns. It is especially useful when noise amplitude has high peaks. (Huang T. Etc. 1979)

$$Unfiltered\ 3\ by\ 3\ matrix = \begin{bmatrix} 5 & 3 & 4 \\ 3 & 10 & 5 \\ 3 & 4 & 5 \end{bmatrix}$$

$$Neighbourhood\ values = 3, 3, 3\ 4, 4, 5, 5, 5, 10$$

$$Median\ filtered\ 3\ by\ 3\ matrix = \begin{bmatrix} 5 & 3 & 4 \\ 3 & 4 & 5 \\ 3 & 4 & 5 \end{bmatrix}$$

Equation 2. Example of median filtering in 3 by 3 matrix.

An example of how the median filter basically works is that we want to reduce peak noise i.e. from the image. In this case all of these individual cells (Equation 2) represent a color value of a pixel and we want to filter all cells that have a value greater than 10. We take all the neighbourhood values, sort them from the smallest to the highest and we simply take the middle of the value which in this case is the value of 4 and then we replace our value which we want to filter. In this case, we replace the value of 10 with the value of 4.

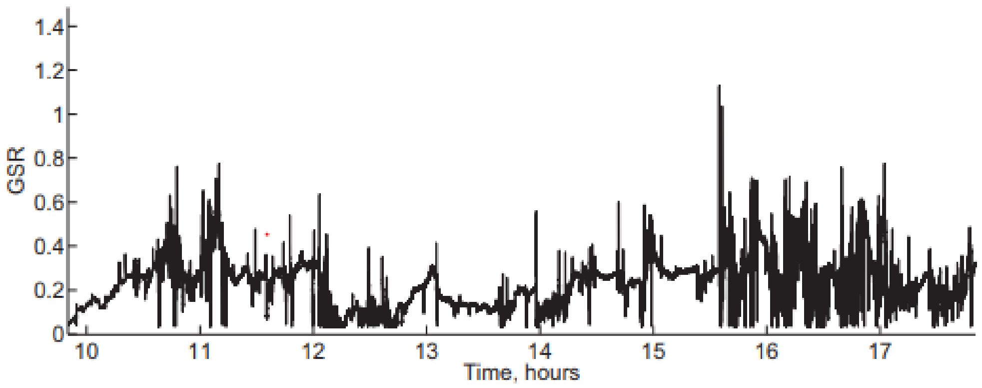


Figure 4. Example of an unfiltered GSR signal (Bakker 2011).

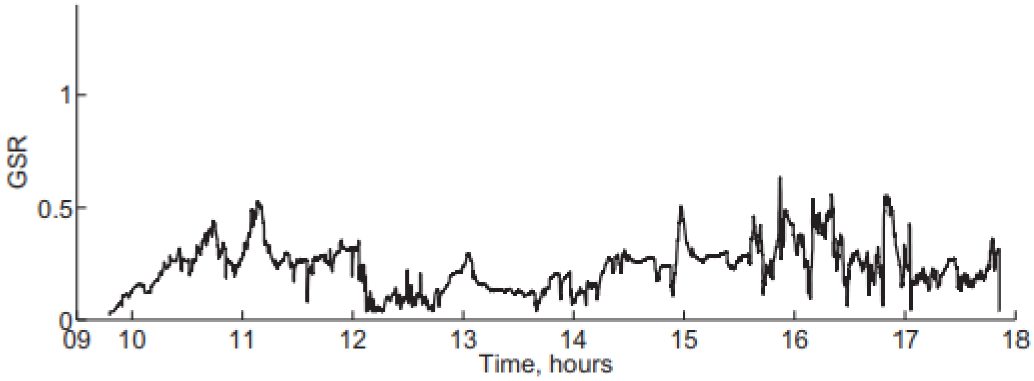


Figure 5. Example of a median filtered GSR signal (Bakker 2011).

According to Jon Bakker's study about detection of stress patterns from GSR sensor data the stress pattern can be divided to four different states which are normal, aroused, stressed and relaxing (Figure 6).

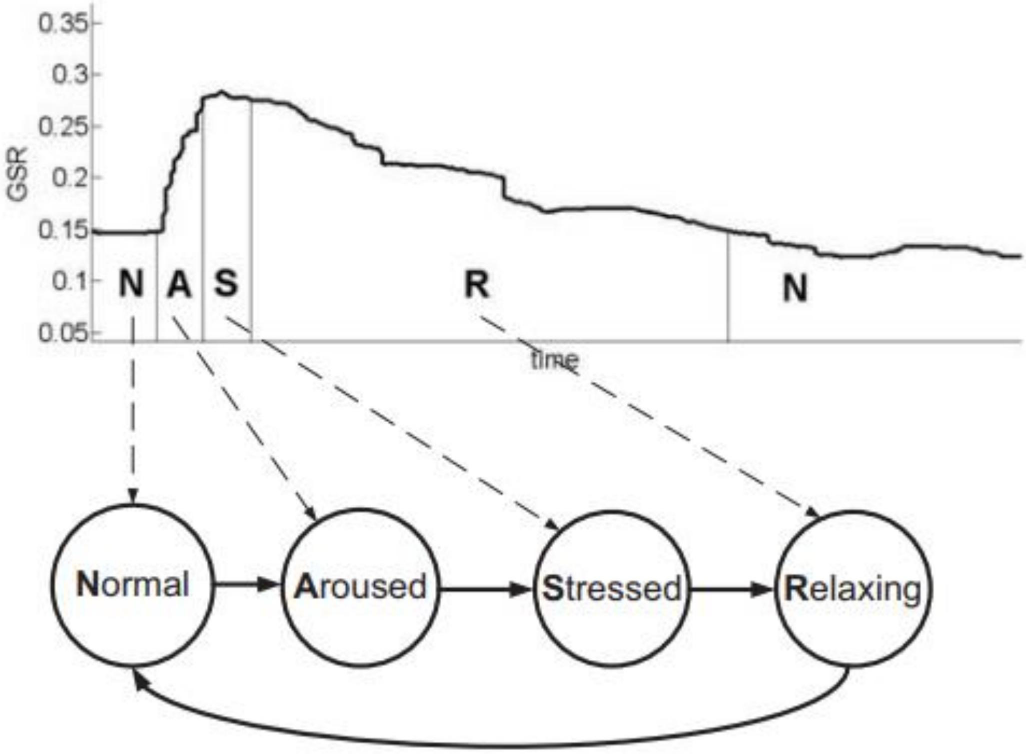


Figure 6. Example of GSR signal acute stress pattern (Bakker 2011)

After getting aroused and then stressed it takes a lot of more time to relax back to normal state. This pattern can be identified from GSR signal after noise is removed. During acute stress body is in a state of alertness and it is controlled by the ANS (Figure 3) (Bakker 2011).

4 CYPRESS PSOC 6

Cypress designs and manufactures microcontrollers and semiconductors. Cypress were founded in 1982 by a Fritz Beyerlein, Fred Jenne, Steven H. Kaplan, T. J. Rodgers R., Michael Stames and Lowell Turriff in California, U.S. (Dataquest 1991). Cypress is leader in advanced embedded systems solutions (Businesswire 2018).

4.1 What is cypress PSoC 6 microcontroller unit

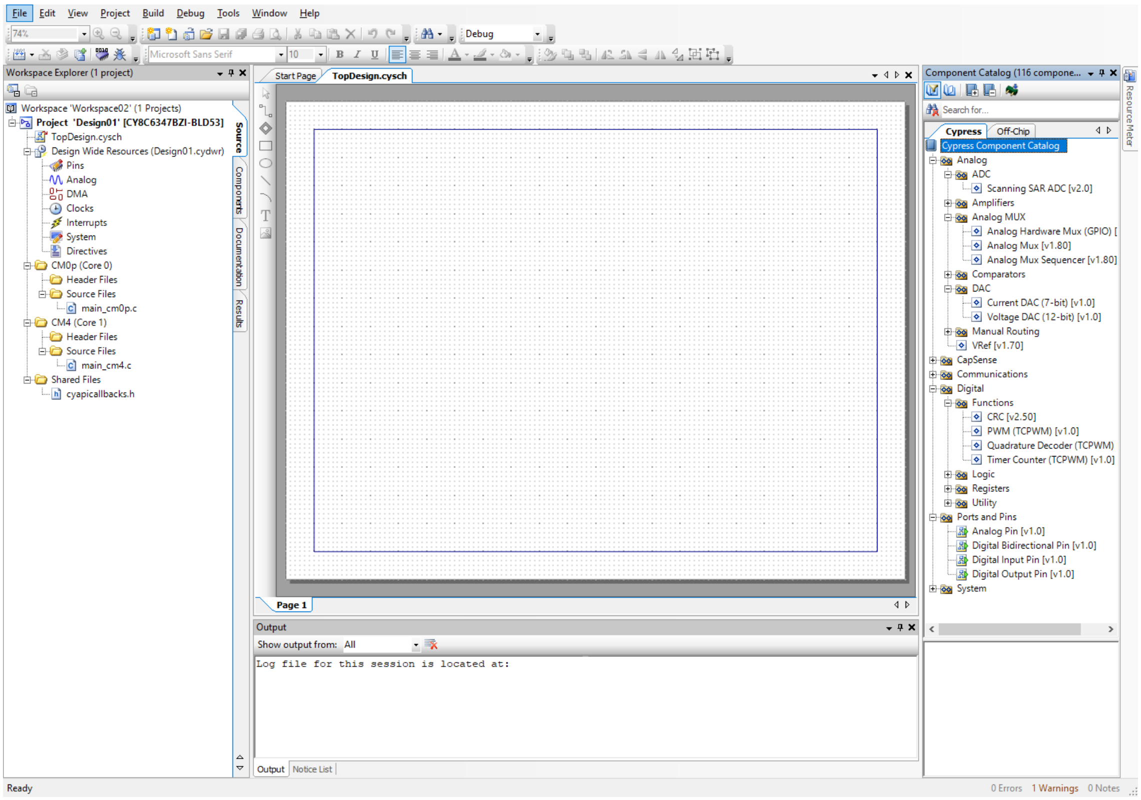
In October 2017 Cypress released their new PSoC 6 microcontroller unit (MCU) (Picture 1) (AudioXpress 2017). PSoC 6 is a low-cost and ultra-low-power MCU which is designed for IoT devices. According to Cypress this MCU eliminates tradeoffs between power and performance. Because it has high power it is perfect for developing wearable devices which need a long battery life. (Cypress 2018)

Picture 1. Cypress PsoC 6 BLE with e-ink display attached.

The Cypress PSoC 6 MCU has a Dual-Core ARM Cortex M4 and M0+ processors which give a good performance with ultra-low-power. It has a Bluetooth Low Energy (BLE), which is used to connect the device remotely to other Bluetooth device, such as Android or iOS smartphones. It uses Type-C port connection to power and simultaneously charge the device. Cypress PSoC 6 BLE Pioneer Kit comes with E-Ink Display Shield which includes some nice features, such as thermistor, 6-axis gyroscope and a microphone. (Cypress 2018).

4.2 PSoC Creator 4.2 - Integrated Design Environment (IDE)

Cypress has created their own IDE, PSoC Creator 4.2 (Picture 2) which is software for making coding easier for their microcontrollers.



Picture 2. Overview of PSoC Creator 4.2 layout.

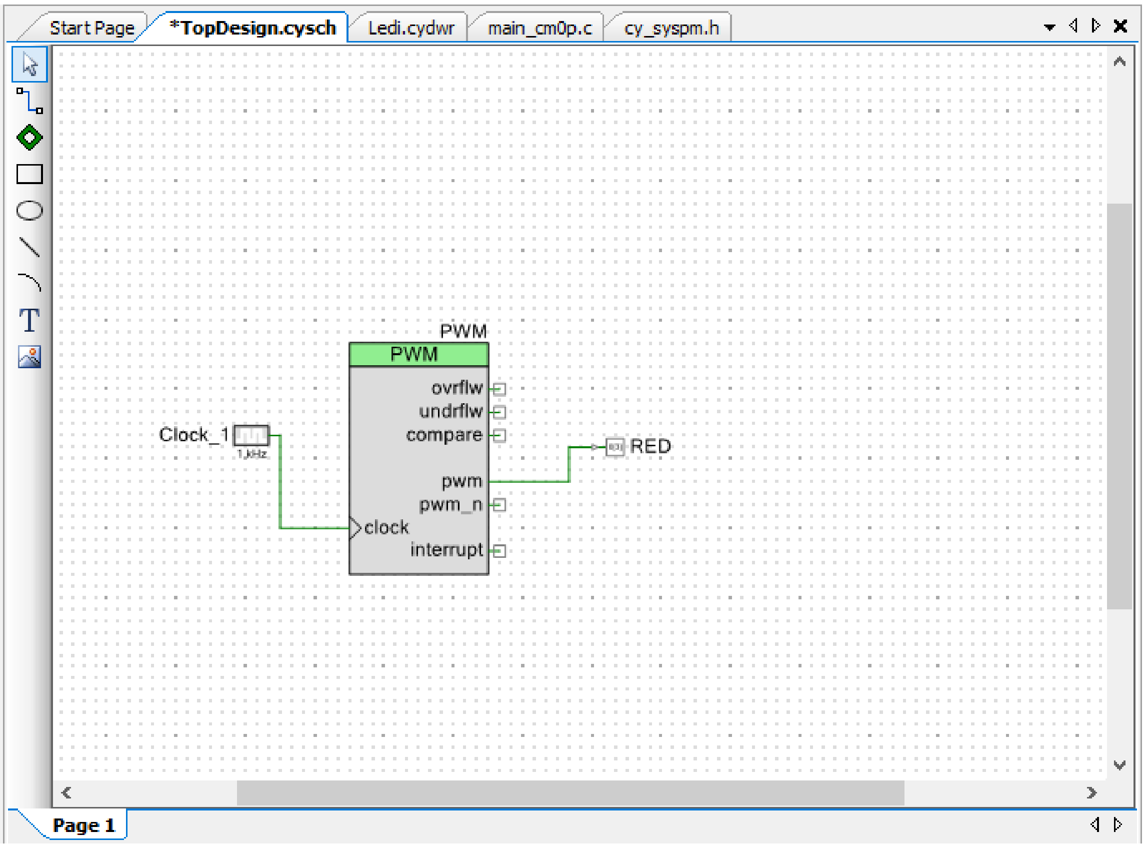
With PSoC Creator, you can edit firmware, compile, debug and run your programs. It has an over 150 drag and drop components included and you can also creat custom components with machine diagrams. It uses a free C source code and there is no limit for code sizes. The newest 4.2 version has Dual-Core workspace which splits source code in separate folders so you always know which core you are currently coding and running. With PSoC Creator, you can also control microcontroller pins, components power modes, frequencies and draw circuit schematics.

4.3 Getting started with Cypress PSoC 6

First thing before starting to work with GSR sensor was to test if the microcontroller actually works and how PSoC creator 4.2 software is used. The Cypress PSoC 6 were just released when this project started, so there are not very much of instructions or code samples provided. The manufacture provided four short introduction videos how to get familiar with the device. One of the videos shows how to code and build blinking red light.

Creating simple design for blinking LED with Pulse-Width Modulation (PWM) were fairly simple. First thing was to create a new empty document which let you choose one of the four target devices or open a device selector. First I used PSoC 62, because on top of the package there is a text that says this device model is PSoC 062-BLE. Which was a mistake that prevented the device function correctly.

Creating schematic for the blinking LED used three components: Clock, PWM and digital output pin (picture 3). Clock component drives PWM component with frequency of 1 kHz. Assigning the digital output pin to P0 and a 3rd pin, which is a red LED in the top right corner of the microcontroller. With Generate Application command the software now automatically creates firmware for the application. After running a Generate Application command, the program creates two main files for coding, main_cm0.c and main_cm4.c. Because this is a dual core microcontroller, the program creates the main file for both cores each. In this project we only need to use one core so we use main_cm0.c and comment out line: `Cy_SysEnableCM4(CY_CORTEX_M4_APPL_ADDR);`. Commenting that line out prevents microcontroller from starting CM4 core, because 2nd core is not used in this blinking led project. PWM component needed to start with simple command: `PWM_Start();`. After that CM0 core needs to put in to sleep to save power. Putting CM0 core in the sleep does not prevent a basic clock oscillator to work, so the led blinks even when the core is in the sleep mode. The CM0 core is set to sleep with a simple command: `Cy_SysPm_Sleep(CY_SYSPM_STATUS_CM0_SLEEP);`



Picture 3. Finished schematic for blinking LED.

The application was ready to be built and according to Cypress Developer introduction video, after build command it should work instantly. Nevertheless it did not. There was also Program button under Debug tab which was unmentioned in the video. This Program button starts the application and runs it to the device. Unfortunately, it still did not start to work. After some research, the problem was caused by the wrong target device, outdated firmware and wrong jumper switch settings. First thing to do was open PSoC Programmer which is the whole different software included with the PSoC Creator software. It recognizes the device and lets you know which is the model of your board. From Utilities tab, firmware had to be updated and flash memory had to be cleaned as well. The microcontroller contains 3 different jumper switches SW5, SW6 and SW7. SW5 needed to set from 1.8v to 3.3V. SW6 has to be in PSoC 6 BLE mode and not in an external device mode. Otherwise the MCU does not recognize that program will be fully controlled with the PSoC 6 MCU. The SW7 switch has to be set in VDDD/KITPROG2 which is onboard programmer/debugger and its used for programming the device. Other option is a super capacitator mode which is used for backup power. After re-building firmware with Generate Application and Build Application, it was possible to run through the Programmer/debugger. The PSoC Creator still needed a right target device. The PSoC Programmer revealed information that the current device is CY8C6347BZI-BLD53 and the selected device was CY8C6347BZI-BLD54. After changing the target device and running Program under the debugger tab the application worked and led started to blink.

4.4 GSR sensor

The GSR sensor used in this project was Grove – GSR sensor made by Seeed studios (picture 4). The sensor has the operating voltage of 3.3V/5V and input signal is resistance, not conductivity. The output signal is voltage which is an analog reading. Because with GSR sensor conductivity is measured, the output signal needs to be converted to match human resistance. The Grove GSR sensor fixes that with the following formula (Equation 3).

$$\frac{((1024 + 2 \times Serial\_Port\_Reading) \times 1000)}{(512 - Serial\_Port\_Reading)}$$

Equation 3. Human resistance.

Serial_port_Reading is the value display on Serial Port which is in this project is COM3 send over UART(Universal Asynchronous Receiver Transmitter). When sending data over I²C (Inter-Integrated Circuit) or SPI (Serial Peripheral Interface Bus) protocols in Cypress PSOC 6 the Serial Port would be KitProg2 instead of COM ports.

5 SETTING UP GROVE GSR SENSOR WITH CYPRESS PSOC 6

The installation guide for the Grove GSR Sensor can be found their website, unfortunately they provide code examples and a software library only for five supported platforms which are Arduino, Raspberry Pi, BeagleBone, Wio and LinkIT One. According to their website it is not possible to provide software libraries for all possible MCU platforms, so users have to write their own software library. Because in this project Cypress PSoC 6 will be used, the code needs to be written from the scratch.

5.1 Connecting

Grove GSR Sensor is compatible with Arduino Base Shield and PSoC 6 is Arduino Shield compatible so it was possible to use Arduino Shield in this project with PsoC 6. Without Base Shield sensor had to be connected directly to the MCU. Seeed Studio provides a table for connecting the wires (Table 1).

Table 1. Wiring Grove-GSR Sensor with Seeeduino.

Seeeduino	Grove-GSR Sensor
GND	Black
5V	Red
NC	White
A0	Yellow

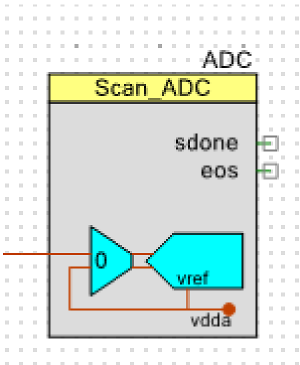
The GSR sensor was connected to the MCU using Grove wiring table as a guide (Table 1). In this project 3.3V connection was used instead of 5V and A0 connection in PsoC 6 is 10.0 input pin. NC stands for No Connection. There is an available spot for NC in PSoC. Connection between the computer and PSoC 6 is established with USB to USB-C cable.

5.2 Components

There are three main components t to get Grove – GSR Sensor up and running with PSoC Creator 4.2. Scanning SAR ADC, Analog Pin and UART communications interface.

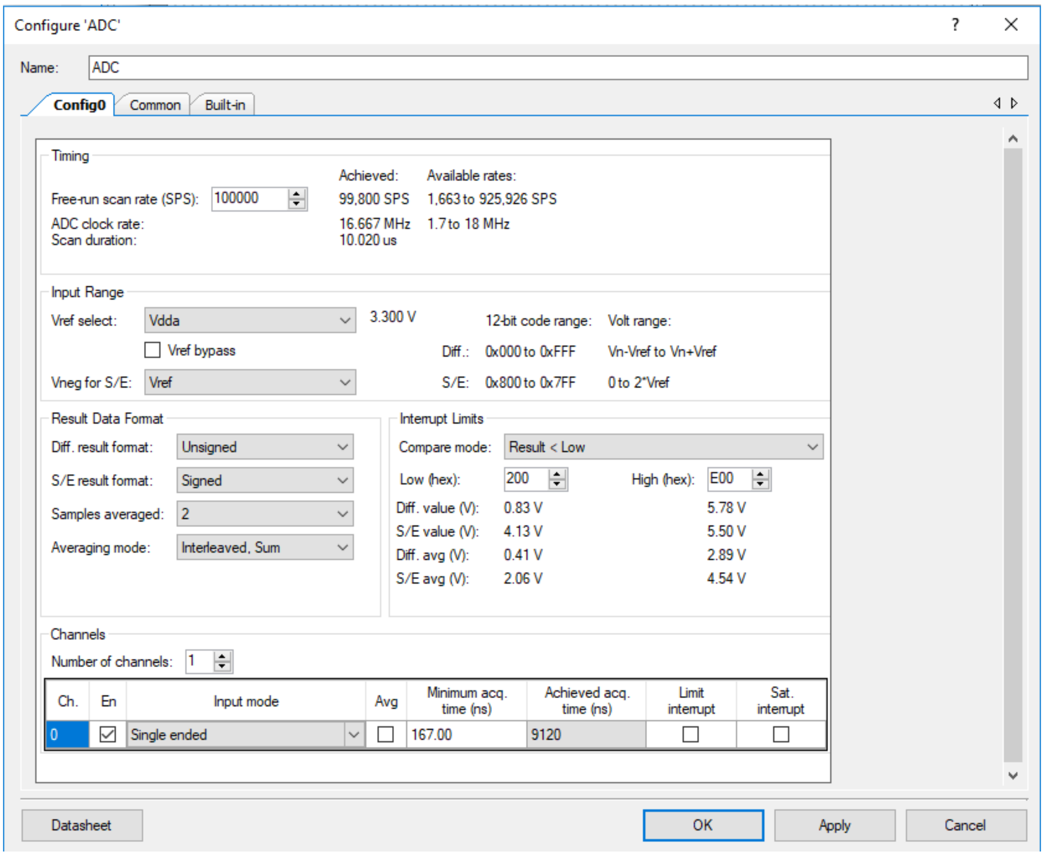
5.2.1 Scanning SAR ADC

The Grove GSR Sensor output signal is analog so Analog-to-digital converter had to be added to our PSoC Creator Project (Picture 4). The Scanning SAR ADC Component can handle up to sixteen analog channels. Only one channel was used, because our GSR sensor has only one output pin.



Picture 4. Scanning SAR ADC Component

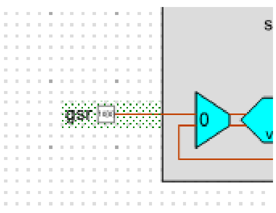
The ADC component had to be configured to our needs (Picture 5). Voltage reference (vref) set as Vdda to get 3.3V input. Vneg for Single Ended (S/E) was set as Vref which input range is 0.0 to Vref*2. Vneg for S/E parameter selects where the negative input to ADC component is connected when the channel is configured for single ended operation. The S/E result format was set signed because data from input pin 10.0 is converted as a 16-bit signed integer. Because only one channel was used, the number of channel had to be set as one. The input mode for the channel was set as single ended because voltage was carried by one wire. With differential signaling minimum 2 wires needs to be used. The ADC component has an average mode included. If the avg. box is checked, it is possible to average samples between 2 and 256 automatically. Average mode was left unchecked because the median filter was added later with UART component.



Picture 5. Scanning SAR ADC Component configuration.

5.2.2 Analog pin

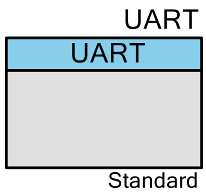
This is a basic connection pin for ADC. ADC component needs an external pin assigned, which is the place where the ADC component reads the analog signal. In this project, the pin is named as gsr (Picture 6), because it was (A0)10.0 pin where GSR Sensor output was connected.



Picture 6. Analog pin

5.2.3 Universal asynchronous receiver-transmitter

Universal asynchronous receiver-transmitter (UART) is an asynchronous communication device for receiving and transmitting data as bits. In this project, UART component (Picture 7) will receive the converted analog data from ADC and it will be sent over communication port to be printed out in a terminal emulator program i.e. TeraTerm.

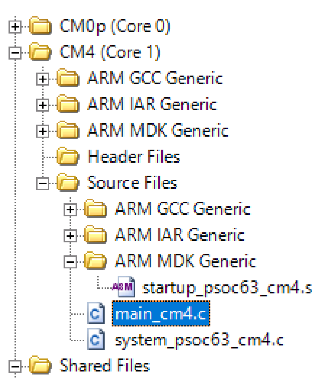


Picture 7. UART component.

UART mode was set as TX + RX so a receiver and a transmitter could be enabled simultaneously. The RX input carries the input serial data from another device on the serial bus. The TX output carries the output serial data to another device on the serial bus. After that digital filter was enabled. This added a digital median filter to the UART input lines.

5.3 Coding the program

In this project, only the main core was used. Code was added under CM4 (Core 1) folder in the main_cm4.c file (Picture 8). CM0p (Core 0) were untouched because it starts the CM4 core. With the blinking led test that line needed to be commented out to prevent CM4 core from starting.



Picture 8. PSoC Creator directory structure

First thing to start creating the code was to add `"#include "stdio.h"` line to enable `sprintf` commands which were used for sending data over UART. Defining transmit_buffer_size to be 16 and defined as character variable while Output was defined as an integer (Picture 9). `ADC_start();` starts the ADC component. After starting ADC, it can receive an analog data.

```c
#include "project.h"
#include "stdio.h"


#define TRANSMIT_BUFFER_SIZE 16

void UartInit(void);

int main(void)
{

    UartInit();

    char TransmitBuffer[TRANSMIT_BUFFER_SIZE];
    int Output;

    ADC_Start();

    __enable_irq(); /* Enable global interrupts. */

```

Picture 9. Basic includes, definitions and how to start the component.

After ADC component was started, `ADC_StartConvert();` command was used for starting the analog to digital conversion (Picture 10). Once conversion is started ADC component runs until it is stopped. In this project, we want it to never stop converting so it will be sending data continuously. `Output = ADC_CountsTo_mVolts(0, ADC_GetResult16(0));` is the line where the data is read and sent to Output integer. The `ADC_CountsTo_mVolts` command takes a channel parameter of 0 which is the channel where GSR sensor was connected. Then `ADC_GetResult16(0);` were command added. 0 is the channel where data were read and returned as a signed 16-bit integer.

```
    for(;;)
    
    {
        ADC_StartConvert();
        Output = ADC_CountsTo_mVolts(0, ADC_GetResult16(0));
        sprintf(TransmitBuffer, "%d\r\n", Output);
        Cy_SCB_UART_PutString(UART_HW, TransmitBuffer);
        CyDelay(500);
    }
}
```

Picture 10. Conversion loop

Now the data had to be printed out so we use `sprintf(TransmitBuffer, "%d\r\n", Output);` command where TransmitBuffer is defined to 16 to handle a 16-bit integer. Embedded format tag `%d` is where output value is printed, `\r` is a carriage return character which tells the terminal emulator to move the cursor at the start of the line and `\n` changes the row in the terminal emulator.

Then data were send over UART to our terminal emulator using `Cy_SCB_UART_PutString` command (Picture 10).

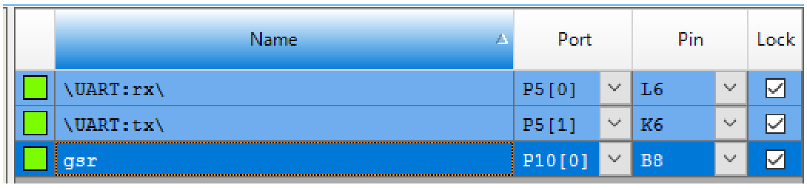
```
void UartInit(void)
{
    /* Configure the UART peripheral.
       UART_config structure is defined by the UART_PDL component based on
       parameters entered in the Component configuration*/
    Cy_SCB_UART_Init(UART_HW, &UART_config, &UART_context);
    
    /* Enable the UART peripheral */
    Cy_SCB_UART_Enable(UART_HW);
}
```

Picture 11. Enabling UART

In march 2018, the PSOC Creator 4.2's peripheral driver library had an update where `UART_Start` command were separated in two different lines of code so UART can be initialized without starting it. This gives a possibility to add more initialization code such as interrupts (Cypress 2018). Because in this project there was no need to add more code, we was initializing UART and component was started straight away with `Cy_SCB_UART_Enable(UART_HW);` command.

5.4 Assigning pins

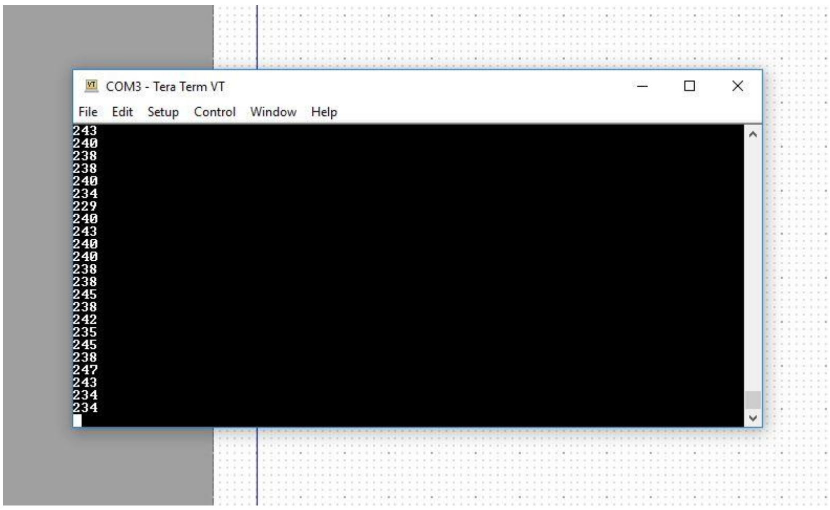
Pins had to be assigned to get lines work properly. UART uses default ports P5[0] for input and P5[1] for output (Picture 12). For analog pin the port needs to be set the same as the GSR sensors Yellow cable (A0) which in this project was P10[0].



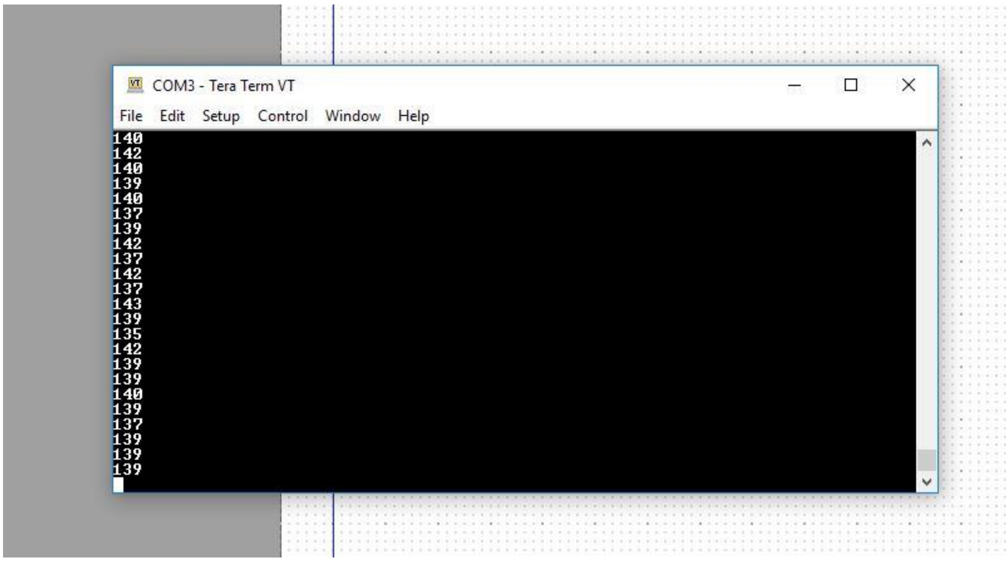
Picture 12. Assigning Pins via PSoC Creator 4.2.

5.5 Sending data over UART to TeraTerm

Data had to be printed out so data were sent and printed in TeraTerm. After programming the code via Psoc Creator debugger, the GSR sensor and MCU was now up and running. Now TeraTerm had to be opened and the connection was selected to be Serial port and in this case we were using COM3 port which was in PSoC 6 named as KirProg2 USB-UART (COM3). By the default TeraTerm Baud Rate (bps) was 9600 and in this project UART component were given bps of 115200. Bps had to be changed from TeraTerm Serial Port Setup to match UART bps. After that data were continuously sent from GSR sensor to MCU and over UART via USB cable to the computer (Picture 13 and 14).



Picture 13. GSR sensor readings when device were not attached to fingers.



Picture 14. Output values when GSR sensor is attached to fingers

According to Grove GSR sensors guide how to setup the sensor, the value when the device is not attached to fingers should be adjusted with the resistor screw until it gives an output as 512. Adjusting the resistor screw had no effect on those output values. It might be caused by a faulty resistor.

6 CONCLUSIONS

The focus of this thesis was to ideate and prototype new assistive technology for people with autism spectrum disorder. The idea behind this technology is very interesting and research shows that human expressions have a very intense correlation through sweating, because our autonomic nervous system is attached to our sweat glands while it also controls our emotions. One of the main concerns is the reliability with the GSR sensor, because the sensor is really sensitive to any disruptions such as hand movement, exercising and for other sudden movements. This creates a lot of noise and reducing or removing noise from the measurement results can be challenging. In the future with long-term testing and highly developed algorithms that could be achievable.

With an only minor knowledge with electronics and microcontrollers using Cypress PSoC 6 were really challenging because the learning curve is really big. The main reason for the high learning curve is the inadequate tutorials and lack of material and coding examples for the most basic stuff. The reason for that is because the PSoC 6 was released just before this project started, so the community for PSoC 6 is fairly new. Cypress already provides impressive amount of tutorials and a very detailed documentation. They have short video tutorials, but even with these tutorials the lack of basic knowledge of microcontrollers makes the simplest tasks almost impossible to get work correctly.

Community is really active and there are a lot of user created projects and code samples. Unfortunately, they are mainly for older Cypress PSoC devices and schematics are unusable, because components are different. PSoC Creator software itself works very well and it has unlimited amount of possibilities to create any microcontroller related project that you can imagine.

Based on this thesis, I would definitely recommend use Cypress PSoC 6 if the user skill level with microcontrollers is greater than medium, otherwise I would use some a more common platform, such as Arduino or Raspberry PI, because you can find a lot of help and information from the internet. Cypress PSoC 6 is really powerful and fast with the latest technology such as a type-C connection and built-in BLE.

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